Special Report

Section IV

August 14, 1941

MASSACHUSETTS INST. TECH
RADIATION LAB
CAMBRIDGE, MA 02139

Not Circulated Outside R. L.

IV-35

Report on Jamming and

Counter-jamming Measures.

The following is an attempt to set down in systematic form the ideas which have been discussed around the laboratory concerning possible means of jamming Radar systems and counter-measures for these. As a prerequisite to successful jamming of a system in use by an enemy, the characteristics of the signals must be determined so the first thing covered will be methods of detection. Following this different types of jamming methods will be considered with regard to their effect on possible radar systems. Finally counter-measures for these will be discussed.

The problem of detecting Radar signals is fundamentally easier than that of providing a receiver for the Radar system itself, since the signal strength at the target object falls off only as the inverse square of the distance to the transmitter, while the intensity reflected back to the transmitter falls off is the inverse power of the distance. Therefore receivers for the detection of an enemy system may be much less sensitive than those used in the system itself. This advantage is partially counteracted by the lack of knowledge of frequency of the signals of the enemy, so that the detecting set may be required to cover a very wide frequency band. There have been at least three types of detecting sets tried or proposed so far. These are:

a) Silicon crystal plus audio amplifier.

b) Superhet receiver ending in phones and output meter.

c) Thermistor bridge with narrow band audio amplifier as detector.

The first of these is suitable only for the detection of modulated signals such as those of a pulse system, while the last two will also find CW signals such as those of a Doppler system. The third is incapable of giving any information as to modulation of received signals, since its indications are proportional to received power averaged over a time of from 0.1 to 1 second.



A set-up of the first type was tried at the Arlington Heights water tower which is about $5\frac{1}{2}$ miles from M. I. T. The system in the screen cage on the roof was directed at the water tower and left stationary during the observations. The field equipment consisted of two of the battery operated amplifiers used with wavemeters which had been arranged to be operated in tandem. Both were used as two-stage amplifiers, giving four stages in all. A pair of headphones was connected to the output. The pick-up consisted of a half-wave dipole feeding a silicon crystal thru a short length of concentric line. No tuning or directional elements were used. Signals were very easily heard in the phones though no deflection of the meter could be observed. Signals persisted with nearly full intensity to within about 3 inches of the ground. Houses were observed to cast fairly sharp shadows. By walking back and forth it was shown that the signal strength was fairly constant over a distance of at least three hundred yards normal to the beam. Bad geography and lack of time precluded any more exact determination of beam size by this method. Subsequently essentially the same equipment was carried in a plane by Griggs.

It has since been found possible to run three of the amplifiers in tandem, so that greater sensitivity may be attained. Furthermore the use of a moderately selective audio amplifier such as the General Radio Sound Analyzer will give still greater usable gain as well as permit a determination of the repetition rate of the signals being received. It is also proposed to use a pick-up consisting of a dipole with a movable reflector mounted behind it which will give some directivity and gain as well as permit rough determination of wave-length. For more accurate determination of wave-length such as would be required in setting the frequency of a jamming signal, the set-up will be arranged to permit connection of one of the laboratory wave meters either between the dipole and crystal detector or on a branch to this line. With these proposed improvements it seems likely that there would be little difficulty in getting the essential information about out system necessary to jam it at distances up to twenty miles.

An outfit of the second type is under construction at the General Radio Company. The first one being built is designed primarily for lower frequencies, from [illegible]00 to 1000 mc. roughly although it will work up to 3000 mc on harmonics at somewhat reduced sensitivity. The sensitivity in its intended range is such that a useable deflection will be secured for a signal of the order of a few microvolts applied at the input terminals. It has an IF amplifier with a band with 2 to 3 megacycles, so that it gives at once an accurate indication of the frequency of the observed signal. However it is necessary to tune thru the frequency range to be covered at a slow enough rate that signals shall not be missed. If one allows a

rate of 3 mc/sec/sec for tuning it takes about fifteen minutes to cover the range from 100 mc to 3000 mc, and if the further range up to 30,000 mc is to be covered the time becomes almost prohibitive. Therefore it seems that this outfit must be supplemented by other means which cover a much wider portion of the frequency spectrum at once whenever a general search is under way.

The third type of detecting system has as its sensitive element the so-called thermistor, a development of the Bell Telephone Laboratories. The thermistor is a semi-conductor such as uranium oxide or nickel-manganese oxide which has a high temperature coefficient of resistance. It is used as a bolometer, the energy to be detected being fed into a thermistor which forms one arm of a Wheatstone bridge. A second thermistor is in the opposite arm of the bridge to compensate for ambient temperature variations, while the other two arms may be made up of condensers or resistors. The bridge is fed by a stable audio-frequency oscillator and the detector consists of a tuned audio amplifier with a band pass a few cycles wide. Calculations reported by Coleman indicate that power as little as $10^{-11}$ to $10^{-12}$ watts in the thermistor might be detected. If reasonably good efficiency of power transfer from an antenna to the thermistor can be obtained, this should give very great sensitivity, typical figures quoted by Coleman being the detection of a 1 watt transmitter at 100 miles. Since the indication results from the temperature change of the thermistor, any modulation in the signal being detected, which is more rapid than the temperature can follow, will be lost. The thermal time constant is from 0.1 to 1 second. It seems likely that the problem of getting good energy transfer from the antenna to the thermistor

lies in the range around one or two hundred ohms. Accordingly the development is to proceed in this direction. It is to be carried out under the direction of J. S. Coleman, who is in Prof. Harrison's section of the NDRC, and is to begin about August 15. They are to develop the unit consisting of the thermistor, bridge, oscillator, and amplifier leaving the problem of getting the energy from an antenna to the thermistor to us.

Having obtained information as to the signal being used by an enemy Radar system, i.e. its wavelength, whether modulated or unmodulated, if modulated whether pulse or frequency modulation, if pulse modulation pulse length and repetition rate, the next step is to provide some sort of signal which will prevent the enemy system from working. The following categories would seem to cover any type of signal which might be useful:

a) Pure continuouse wave signals (CW).

b) Amplitude-modulated continuouse wave ( AM CW )

c) Frequency - modulated continuous wave ( FM CW)

d) Amplitude and frequency modulated (AMFM CW)

e) Pulse signals

The first of these, as its name implies, consists of a pure carrier at the frequency to which the enemy receiver is tuned, of such intensity as to give a signal in the enemy receiver which will paralyze it. The second, third and fourth, involve the addition of the indicated type of modulation to the carrier. The fifth involves the transmission of pulse signals in answer to those of the enemy, perhaps delayed by nearly the time between successive pulses so that the jamming pulses may appear to come in before as well as after the true echo in the enemy receiver. This would have as its object merely th

[redacted]





vention of his obtaining the correct range rather than the complete paralysis of his receiver, and so might be expected to be more useful against fire-control Radar.

The usefulness of the various types of jamming is probably best discussed in terms of their effect on various possible types of Radar systems. It seems to be necessary to specify at least three elements of the system, the type of transmitter, the type of receiver, and the method of direction control, whether relatively fixed as in search or GL, or scanning as in AI. At least five combinations seem to be useful, and may be described as follows:

a) Pulse transmitter, IF receiver, fixed direction.

b) Pulse transmitter, video receiver, fixed direction.

c) CW transmitter, video (or audio) receiver, fixed direction.

d) Pulse transmitter, IF receiver, scanning.

e) Pulse transmitter, video receiver, scanning.

A sixth combination, a CW system with scanning, is omitter as probably being of little practical use. This is in accord with the views of Hansen, one of the chief proponents of CW systems. Possible systems employing frequency modulation such as the WE absolute altimeter are not considered since they seem to be of little use in Radar work. The receivers are described by the means used in securing most of the gain, which has an important bearing in their susceptibility to CW jamming. Our typical AI system is accordingly combination d) while the GL systems are essentially combination a). The various combinations will now be discussed one at a time with regard to the effects of the different types of jamming signals and counter measures will be indicated as the discussion proceeds. Finally the whole thing will be gathered in tabular form. [redacted]

[redacted]





The first type of system, namely one employing pulse transmitter, IF receiver, and fixed direction, is susceptible to all of the types of jamming. The effect of any of the cw methods, whether modulated or unmodulated is to furnish so large a signal at the second detector as to make it inoperative for the desired signals. A conceivable counter measure in the case of CW or AM CW is the elimination of a band of frequencies containing the interfering signal in the receiver response. Circuits for this are available at least in low-frequency narrow band amplifiers, but it seems likely that they would seriously degrade the performance of a wide-band pulse amplifier, with regard to the sharpness of pulse and speed of recovery after overload. A jamming signal which is frequency-modulated over a range equal to the response of the receiver cannot be eliminated by such a band-rejection scheme. About the only remedy available here seems to be change of transmitter and receiver frequency, either systematically or at random. Development work is going on looking towards the production of an automatic tuning system which will automatically keep the receiver tuned to the transmitter provided the frequency does not vary too far or too rapidly. It would seem that shifts of the order of 10mc should be enough to counter most jamming signals. If the jamming station attempts to cover such a wide range by frequency modulation, there will be enough of the time when the jamming does not get thru the receiver so that some signals could be received in the intervals.

As mentioned before, jamming by pulse transmission would have as its object only interfering with range determination. This would be accomplished by having a transmitter on the target object which is so arranged as to send back one or several pulses every time a pulse from the Radar system comes along. By delaying some of the pulses



[redacted]

by nearly the time between successive signals, the indicator in the receiver could be made to resemble a whole series of objects, some nearer and some further away than the actual target. A possible counter measure here is either random or systematic variation in repetition rate of pulses. This would have the effect of making all jamming pulses which are returned with long delay appear at a variable time in front of the succeeding pulse, so that they would not look like a true sharp signal. It would probably be sufficient to make the time between pulses say alternately 490 and 510 microseconds. With such a system the first sharp signal would be the correct one.

The second type of system, pulse transmitter, video receiver fixed direction, differs chiefly from the first in that it is not particularly susceptible to jamming by a pure CW signal, since such a signal will not get beyond a stage corresponding to the second detector of a superhet, while the proposed receiver has most of its gain after this point. On the other hand, band rejection circuits would be much harder to apply to such a receiver, although in the case of AMCW jamming it might be possible to eliminate the modulation frequency of the jamming signal by similar means.

The third type of system, CW transmitter, audio receiver, with fixed direction, is exemplified by the set-up used at the Loomis lab and those used by Hansen. It is fundamentally different from the toher systems in that it uses a narrow band receiver. This has several important consequences, the most important being that a jamming signal must be extremely accurately located in order to affect the system at all. Furthermore, since the transmitter in this system effectively serves as the local oscillator for the receiver, the

problem of shifting frequency to avoid jamming becomes much easier.

Going along with these factors, there is probably greater difficulty in detecting such a system to begin with, since the average power used is probably about the same as in a pulse system, which means that the peak power is much smaller, so that with a detection receiver which must be wide band to cover the frequency spectrum in a reasonable time, the small peak power is a considerable disadvantage. This probably would not be true to such an extent with the thermistor bridge as a detector. However, once detected, the frequency of the jamming signal must be much more accurately adjusted, to within a few kc as compared to one or two mc in the pulse system.

The fourth type of system differs from the first only in that it is scanning rather than fixed direction. This causes no new features in jamming or counter-jamming, except that all methods of jamming give away the idrection of the jamming outfit, and with good directivity in the Radar system it should be possible to work in other directions without much interference.

The fifth type differs from the second again by the use of scanning. This adds some susceptibility to jamming by a CW signal, since in sweeping past the direction of the jamming, that signal is effectively modulated by the directivity pattern of the receiver. It should be possible to reduce the low-frequency response of the receiver to such an extent that this modulation is not passed, while the pulses are left undisturbed. A Fourier series expansion of the directional pattern of the antenna expressed in proper units would give the energy distribution as a function of frequency and so show where such a cut-off should be made. With regard to other types of jamming the situation is unchanged.

| | CW | AMCW | FMCW | AMFMCW | Pulse |
|---|---|---|---|---|---|
| Pulse T | 1 | 1 | 1 | 1 | 1 |
| IFdeo R | 2 | 2 | | | 3 |
| Fixed D | | | | | |
| Pulse T | | 1 | | 1 | 1 |
| Video R | | 2 | | | 3 |
| Fixed D | | | | | |
| CW T | 1 | 1 | | | |
| Audio R | | | | | |
| Fixed D | | | | | |
| Pulse T | 1 | 1 | 1 | 1 | 1 |
| IF R | 2 | 2 | | | 3 |
| Scan | | | | | |
| Pulse T | 1 | 1 | | 1 | 1 |
| Video R | 4 | 2 | | | 3 |
| Scan | | | | | |

The types of system are shown at the side, while types of jamming are shown across the top. The entries in the table refer to possible counter measures according to the following list.

1) Random or systematic variation of transmitter and receiver frequency.

2) Band rejection in receiver.

3) Random or systematic irregularity in pulse repetition

4) Raise low frequency cut-off of receiver.

Where there is no entry in the table, the type system is not subject to jamming by that means.

The following more or less obvious conclusion may be listed. First, it would be advantageous to have a transmitter that is capable of frequency shift of the order of 10 mc. and a receiver with automatic tunning that can follow at least that far. Furthermore, a self-synchronous system, rather than on driven from a master oscillator, may have advantages in avoiding jamming as well as those connected with the use of more efficient modulators. Finally, work should be done on the exact effect of signals of the various types and of approximately known power on the different types of receiver such as Harvey L, Harvey A and perhaps also an all video receiver which would have to be constructed.

[redacted]